Western North Pacific Tropical Cyclone Formation and Structure Change in TCS08

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LONG-TERM GOALS

The long-term goal of this project is to develop a better understanding of mesoscale and synoptic-scale processes associated with the entire life cycle of tropical cyclones in the western North Pacific. The inability to correctly identify tropical cyclone formation over the period of 24 h – 48 h poses a threat to shore and afloat assets across the western North Pacific. Furthermore, once a tropical cyclone has formed the predictability of structure changes during intensification of tropical cyclones is very low, which is due to complex physical processes that vary over a wide range of space and time scales. Periods of reduced predictability occur throughout the tropical cyclone life cycle, which includes the decaying stage. Because decaying tropical cyclones often transition to a fast-moving and rapidly-developing extratropical cyclone that may contain gale-, storm-, or hurricane-force winds, there is a need to improve understanding and prediction of the extratropical transition phase of a decaying tropical cyclone. The structural evolution of the transition from a tropical to an extratropical circulation involves rapid changes to the wind, cloud, and precipitation patterns that potentially impact maritime and shore-based facilities.

OBJECTIVES

A primary objective is to increase understanding of the formation of a tropical cyclone from what may have been a disorganized area of deep convection or a weak pre-existing cyclonic disturbance. Over the monsoon environment of the tropical western North Pacific, pre-tropical cyclone disturbances range from low-level waves in the easterlies to large monsoon depressions. An objective of this project is to define factors that impact the large-scale atmospheric and oceanic controls on tropical cyclone formation.

A long-term goal is to understand the relative role(s) of mesoscale processes in organizing a pre-tropical cyclone disturbance such that it may begin to intensify as a tropical cyclone. A specific objective is to examine processes that define relative contributions of low-level vorticity in deep convective towers versus mid-level circulations embedded in stratiform regions of mature mesoscale

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convective systems. This objective addresses the predictability associated with the location, timing, and rate of tropical cyclone formation over the western North Pacific.

Additional objectives address the characteristic structure changes as a tropical cyclone intensifies, matures, then proceeds into extratropical transition. A particular focus is identification of key structural characteristics that limit the predictability of recurvature and the start of the extratropical transition process.

APPROACH

The Tropical Cyclone Structure-2008 (TCS-08) program and the Impact of Typhoons on the Ocean (ITOP) program resulted in direct observations of the entire life cycle of tropical cyclones over the western North Pacific. This included development and non-development of tropical cloud clusters, intensity and structure changes of mature tropical cyclones, and decay and extratropical transition of poleward-moving tropical cyclones. Additionally, several of the typhoons that were sampled exhibited intensity changes associated with varying ocean and atmospheric conditions.

Several studies of processes associated with the formation (Park and Elsberry 2013, Park et al. 2013), intensification (Grams et al. 2013), and extratropical transition (Quinting et al.. 2013, Foerster et al. 2013) have utilized the unique data sets from TCS08. These studies utilized numerical simulations, analyses of aircraft dropsonde and radar data, plus remotely-sensed observations. Additionally, analyzed fields from the European Center for Medium-Range Weather Forecasts (ECMWF) were examined to define characteristics of pre-tropical cyclone circulations over the western North Pacific (Beattie and Elsberry 2013a,b).

WORK COMPLETED

Electra Doppler Radar (ELDORA) data obtained during the TCS08 field program were analyzed to define vertical heating profiles during periods of convective activity in developing and non-developing tropical circulations. Additionally, ELDORA data were utilized to specify the detailed structure of a non-developing cloud cluster during TCS08. An ensemble Kalman Filter data assimilation procedure was derived to assimilate ELDORA data for use in high resolution simulations of a non-developing cloud cluster.

Combined ECMWF analyses and remotely-sensed data were used to define characteristics of monsoon depressions as precursor disturbances to tropical cyclones. A climatological approach was taken to examine spatial and temporal characteristcs.

Analyses of aircraft-deployed AXBTs colocated with dropwindsondes was begun to identify relative contributions from internal storm processes and environmental factors with respect to tropical cyclone structure and intensity change. These analyses were applied to Typhoon (TY) Malakas during the ITOP field program as the storm passed through the southern eddy zone of the western North Pacific under the influence of an upper-level atmospheric trough.

RESULTS

The impact of vertical wind shear on a tropical cyclone as it enters the baroclinic zone of the midlatitudes has rarely been observed. However, this portion of the extratropical transition process is

important for defining the overall storm structure, asymmetric wind structure that contributes to high seas, and storm translation that results in large uncertainty with respect to the storm location. The use of ELDORA data during the movemnt of TY Sinlaku into the midlatitudes allowed clear identification of variations in storm structure by defining quadrants based on the front and rear portions of the storm and the direction of the shear vector (Fig. 1). Maximum reflectivity and winds were found on the upshear and downshear left quadrants. These patterns were identified via a novel that allows for the extremely dense set of radar observations to be analyzed with respect to a background field defined from the operational ECMWF analyses (Bell et al. 2012).

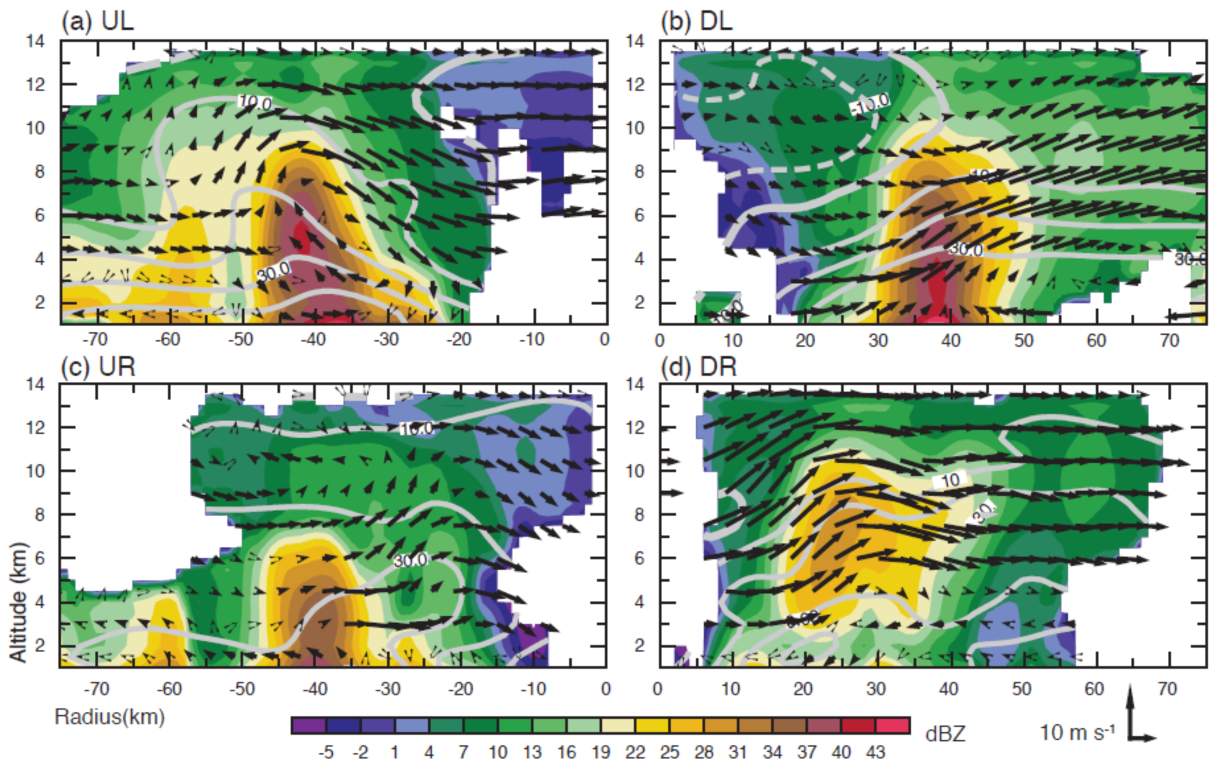

Figure 1. Vertical cross sections of radar reflectivity in dBZ (shaded), tangential wind in m s-1 (gray contours), and in-plane wind vectors composed of radial and vertical velocity for each shear relative quadrant. Cross sections are taken from the corner of the domain to the center, 45 degrees from the X and Y axes in each quadrant. (from Foerster et al. 2013).

Application of the analysis technique for ELDORA data to the final stage of extratropical transition of TY Sinlaku during TCS08 revealed the source of air parcels that defined the major airstreams that define the final extratropical stage of the extratropical transition process (Quinting et al. 2013). In this case, the warm conveyor belt, cold conveyor belt, and dry air stream were identified in relation to air that originated in the tropical cyclone or air that originated at upper levels and high latitudes as part of the midlatitude upstream trough. The results of Foerster et al. and Quinting et al. provided for the first time the structural evolution of a tropical cyclone to an extratropical cyclone, which represents a particular threat to maritime activities over subtropical latitudes of tropical cyclone ocean basins.

The impact of ocean characteristics relative to internal tropical cyclone dynamics has been examined relative to defining the maximu potential intensity that a storm may achieve (Lin et al. 2013). In this study, the use of detailed sub-surface ocean factors as a control on maximum potential intensity was examined. The unique set of tropical cyclones and in situ observations obtained during ITOP provided for the analysis of a new ocean-cooling based intex for maximum storm intensity.

An important aspect to accurate prediction of tropical cyclone structure and intensity changes is to increase understanding of the relative roles of ocean and atmospheric factors. Intensity and structure changes in TY Malakas during the ITOP field program were examined relative to the passage over a set of ocean eddies under the influence of an upper-level atmospheric trough. Malakas reached peak intensity while over cold sea-surface temperatures and low values of ocean heat content as the atmospheric conditions were favorable for outflow channels to the midlatitudes and an increased secondary circulation (Harr et al. 2013).

IMPACT/APPLICATIONS

The research being conducted on the comprehensive data sets gathered during the TCS-08 field program will result in increased accuracy associated with the prediction of tropical cyclone formation, intensification, and structural changes. These improvements will be defined in part through improved numerical simulations using high-resolution models such as the Coupled Ocean Atmosphere Mesoscsale Prediction System – Tropical Cyclone (COAMPS-TC). Additionally, the unique observations of the air-ocean conditions in the environment of mature tropical cyclones over the western North Pacific provide a unique capability to identify the relative roles of environmental factors on tropical cyclone intensity change.

TRANSITIONS

Following the compilation and analysis of the wide range of TCS-08 data sets, research results that identify factors responsible for the variability in tropical cyclone formation, intensification, and structure change will transition into a variety of products that will benefit operational forecasting of these tropical cyclone characteristics. These may be stand-alone products, satellite-based products, improvements to numerical models, etc. Final transition of the research will result in increased predictability associated with tropical cyclones that impact operations of the U.S. Navy across the western North Pacific

RELATED PROJECTS

The analysis of tropical cyclone sturcture and intensity changes is being conducted in relation to several other projects sponsored by ONR Marine Meteorology. One project titled NASA Hurricane and Severe Storm Sentinel (HS3) Observations for Testing Environmental Control of Hurricane Formation and Intensification (N0001412WX21567) is examining data obtained during Hurricane and Severe Storms Sentinel experiment. The relationships among tropical cyclone structure and intensity changes to upper-level outflow is being examined in the project titled Tropical Cyclone Intensity and Structure Changes in relation to Tropical Cyclone Outflow (N0001413AF00002).

REFERENCES

Bell, M. M., M. T. Montgomery, and K. E. Emanuel, 2012: Air-sea enthalpy and momentum exchange at major hurricane wind speeds observed during CBLAST. J. Atmos. Sci., 69, 3197—3222.

Foerster, A. M., M. M. Bell, S. C. Jones, and P. A. Harr, 2013: Observations of the eyewall structure of near-extratropical Typhoon Sinlaku (2008) in vertical wind shear. *Mon. Wea. Rev.,* submitted.

Harr, P. A., H. M. Archambault, and C. –C. Wu, 2013: Air-ocean factors throughout the formation and intensification of Typhoon Malakas during the Impact of Typhoons on the Pacific (ITOP) field program. Davos Atmosphere and Cryosphere Assembly DACA-13. July 2013.

PUBLICATIONS

Beattie, J. C., and R. L. Elsberry, 2013a: Horizontal structure of monsoon depressions in the western North Pacific at formation time. *Geophys. Research Letters*, **40**, 983-987. (refereed)

Beattie,J, C., and R. L. Elsberry, 2013b: Western North Pacific monsoon depression formation. *Weather Forecast*. **27**, 1413-1432. (refereed)

Elsberry, R. L., L.-S. Chen, J. Davidson, R. Rogers, Y. Wang, and L. Wu, 2013: Advances in understanding and forecasting rapidly changing phenomena in tropical cyclones. *Tropical Cyclone Research and Review*, **2**, 13-24. (refereed)

Foerster, A. M., M. M. Bell, S. C. Jones, and P. A. Harr, 2013: Observations of the eyewall structure of near-extratropical Typhoon Sinlaku (2008) in vertical wind shear. *Mon. Wea. Rev.,* submitted. (refereed)

Grams, C. M., S. J. Jones, C. A. Davis, P. A. Harr, and M. Weissmann, 2012: The impact of Typhoon Jangmi (2008) on the midlatitude flow. Part I: Upper-level ridgebuilding and modification of the jet. *Quart. J. Roy. Meteor. Soc.* Doi:10.1002/qj2091 (refereed)

Lin, I. I., P. Black, J. F. Price, C.-Y. Yang, S. S. Chen, C.-C. Lien, P. A. Harr, N.-J. Chi, C.-C. Wu, and E. A. D'Asaro. An ocean coupling potential intensity index for tropical cyclones. *Geophysical Research Letters*, 40, 9, DOI:10.1002/grl.50091. (refereed)

Keller, J. H., S. C. Jones, and P. A. Harr, 2013: An eddy kinetic energy view on physidal and dyamical processes in distinct forecast scenarios for the extratropical transition of two tropical cyclones. *Mon. Wea. Rev*., submitted. (refereed).

Park, M.-S., and R. L. Elsberry, 2013: Latent heating and cooling rates in developing and non-developing tropical disturbances during TCS-08: TRMM PR versus ELDORA retrievals, *J. Atmos. Sci.*, **70**, 15-35. (refereed)

Park, M.-S., A. B. Penny, R. L. Elsberry, B. J. Billings, and J. D. Doyle, 2013: Latent heating and cooling rates in developing and non-developing tropical disturbances during TCS-08: Radar-equivalent retrievals from mesoscale numerical models and ELDORA. *J. Atmos. Sci.*, **70**, 37-55. (refereed)

Quinting, J. F., M. M. Bell, P. A. Harr, and S. C. Jones, 2013: Structural characteristics of T-PARC Typhoon Sinlaku during its extratropical transition. *Mon. Wea. Rev.*, submitted. (refereed)

Presentations

Harr, P. A., H. M. Archambault, and C. –C. Wu, 2013: Air-ocean factors throughout the formation and intensification of Typhoon Malakas during the Impact of Typhoons on the Pacific (ITOP) field program. Davos Atmosphere and Cryosphere Assembly DACA-13. July 2013.

Harr, P. A., H. M. Archambault, and C.-C. Wu, 2013: Air-ocean factors during the passage of Typhoon Malakas over the southern eddy zone of the western North Pacific. 16th Cyclone Workshop, St. Adele, Quebec, September 2013.